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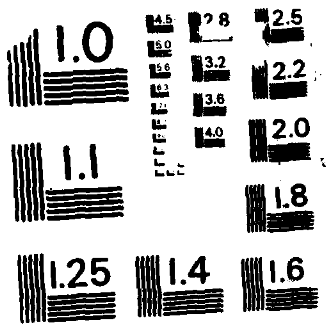

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FIELD INVESTIGATION OF A NEOPRENE
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This report represents a field investigation of a neoprene pad capping system (NPCS) that is marketed as an alternative to the capping materials referred to in CRD-C 29 (ASTM C 617), Standard Practice for Capping Cylindrical Concrete Specimens. The NPCS consists of reusable neoprene pads in steel retainer cans.

The results indicate that within the range of 500 to 5,500 psi, the NPCS appears to be an acceptable alternative to sulfur-mortar caps for testing the compressive strength of 6-in.-diameter by 12-in.-high cylindrical concrete specimens. The NPCS also eliminates a potential safety hazard resulting from working with the sulfur mortar and could constitute a substantial cost savings.

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PREFACE

This report was prepared at the Structures Laboratory (SL) of the US Army Engineer Waterways Experiment Station (WES) and the U.S. Army Engineer District, New Orleans (LMN), under the sponsorship of the Headquarters, US Army Corps of Engineers (HQUSACE), as a part of Civil Works Investigation Studies Work Unit 31138, "New Technologies for Testing and Evaluating Concrete."

The study was conducted under the general supervision of Mr. Bryant Mather, Chief, SL, Mr. John Scanlon, then Chief, Concrete Technology Division (CTD), SL, and Mr. Frederic M. Chatry, Chief, Engineering Division (ED), LMN; and under the direct supervision of Mr. Kenneth L. Saucier, Chief, Concrete and Evaluation Group, CTD, SL; Mr. Rodney P. Picciola, Chief, Foundations and Materials Branch (F&M), ED, LMN; and Mr. Steve Ragan, CTD, SL, the Principal Investigator. The field work was directed by Mr. Ragan and Mr. Dick Rogers, Construction Division, LMN, assisted by Old River Control Auxiliary Structure project personnel. The report was prepared by Mr. Billy Neeley, CTD, SL, and Mr. Robert J. Becker, Chief, Materials Section, F&M, ED, LMN.

COL Dwayne G. Lee, CE, is the present Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
inches	0.0254	metres
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.45359237	kilograms

FIELD INVESTIGATION OF A NEOPRENE PAD CAPPING SYSTEM

PART I: BACKGROUND, PURPOSE, AND SCOPE

Background

1. Cylindrical concrete specimens to be tested for compressive strength are prepared according to CRD-C 29 (ASTM C 617), Standard Practice for Capping Cylindrical Concrete Specimens, and tested according to CRD-C 14 (ASTM C 39), Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. Previous work[1] indicated that:

- a. High circumferential stresses are likely to develop in rings placed around the ends of test specimens to confine gypsum-plaster-capping compound.
- b. Low-strength capping material (<3000 psi) should be used only for capping low-strength concrete specimens and then only if high-strength material is not available.
- c. Lubricant on the cap of a compressive test specimen has no effect on the compressive strength if the thickness is very slight as would result from wiping with a greasy cloth.

2. Recently, reusable neoprene pads inserted into steel retainer caps have been introduced as a possible alternative to the capping materials referred to in CRD-C 29, neat cement mortar, high strength gypsum plaster, and sulfur mortar. Several state highway departments have used the neoprene pad capping system (NPCS) with at least two states adopting its use (Deets 1987)[2]. The American Association of State Highway and Transportation Officials (AASHTO) has approved the use of the NPCS (AASHTO 1986)[3]. The American Society for Testing and Materials (ASTM) presently has a task group working on developing a standard (Deets 1987)[2].

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[1] Saucier, K. L. 1972. "Effect of Method of Preparation of Ends of Concrete Cylinders for Testing," Miscellaneous Paper C-72-12, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

[2] Personal Communication, 3 June 1987, John Deets, Tennessee Valley Authority.

[3] AASHTO, 1986. "Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens," Designation: T-22-86, Annex "Compressive Strength of Cylindrical Concrete Specimens Using Neoprene Caps," Washington, D.C.

Purpose

3. During the construction of the Old River Control Auxiliary Structure (ORCAS) from 1982 to 1985, it was decided to test a number of concrete compressive strength specimens using the NPCS in addition to those capped with sulfur mortar. The purposes of this study were (a) to determine if the differences in the compressive-strength test results obtained using the NPCS and those obtained using sulfur-mortar caps were statistically significant, (b) to compare the within-batch variability of two capping methods, and based on these results, (c) determine if the NPCS might be a viable alternative to present capping methods.

Scope

4. The Corps of Engineer ORCAS project personnel coordinated the investigation with the U.S. Army Engineer Waterways Experiment Station (WES) personnel. WES purchased the NPCS and loaned it to ORCAS project personnel for use from January to May 1985. A total of 262 cylinders were tested for compressive strength using the NPCS.

5. The Old River Control Complex is located about 50 miles northwest of Baton Rouge, Louisiana. Its basic purpose is to prevent the Atchafalaya River from capturing the Mississippi River. The ORCAS is located on the west bank of the Mississippi River at mile 311.4. Its purpose is to operate in conjunction with the low-sill structure and to reduce the flow and pressure on the low sill, thereby improving the capability for dealing with emergencies that could occur at either structure. The ORCAS contains about 220,000 cu yd of concrete. Eight concrete mixtures were used with differences consisting mainly of specified compressive strengths, nominal maximum size of aggregate, and the use of class C fly ash to make up 20 percent of the cementitious material in some mixtures.

PART II: MATERIALS, MIXTURES, AND TESTS

Materials

6\. The project materials were as follows:

- a. Crushed limestone coarse aggregates
- b. Natural gravel coarse aggregate (mixture G-2)
- c. Natural sand fine aggregate
- d. Type II portland cement
- e. Class C fly ash
- f. Water-reducing admixture (WRA)
- g. Air-entraining admixture (AEA)
- h. High-range water-reducing admixture (HRWRA) (mixture J)

7\. The sulfur mortar used was a commercially available material meeting the requirements of CRD-C 29. The NPCS consisted of two retainer caps machined from hot-rolled steel and neoprene pads cut to fit snugly inside the retainer caps. The inside diameter of the steel retainer cap was large enough to allow the concrete specimen to be placed easily into the ring, but small enough to prevent the outer edge of the neoprene pad from flowing around the ends during loading. The neoprene pads were classified by the manufacturer as being appropriate for testing concretes having compressive strengths in the range from 3,000 to 7,500 psi. A sketch of the steel retainer cap and of the neoprene pad are given in Figures 1 and 2, respectively. The cost of the NPCS was as follows:

a.	Steel retainer caps (6-in. diameter)	$120 / set
b.	Neoprene pads (6-in. diameter)	$ 12 / set

The manufacturer of the NPCS indicates that the neoprene pads should be replaced when they show significant physical deterioration or when they have been used a maximum of 300 times. The steel retainer caps can be used for an indefinite period of time. They should be checked periodically to verify the planeness requirements for machined bearing blocks specified in CRD-C 14 (ASTM C 39).

Mixtures

8. Specimens were tested from seven project mixtures. Proportions for the seven mixtures are given in Table 1.

Tests

9. The compressive strength specimens were 6-in. diameter by 12-in. high cylinders made and cured according to CRD-C 11-83 (ASTM C 31-83), Standard Method of Making and Curing Concrete Test Specimens in the Field, until tested at 7-, 28-, and 90-days age. The 1-day accelerated cured specimens were made according to CRD-C 11 and cured and tested according to CRD-C 97-81 (ASTM C 684-81), Standard Method of Making, Accelerated Curing, and Testing of Concrete Compression Test Specimens, Procedure A. Four companion specimens from each mixture were tested at each age. Two companion specimens were tested according to CRD-C 14-83 (ASTM C 39-81), Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. The ends were capped with a sulfur mortar prior to testing. The two remaining companion specimens were tested using the NPCS. One set of neoprene pads was used to test the 262 cylinders. The pads showed considerable wear when all testing was completed. The test results are given in Table 2.

PART III: RESULTS

Overall Variations

10. The compressive strength data were sorted according to mixture, age, and type of cap. The mean, standard deviation, range, and coefficient of variation for each group are given in Table 3. In order to determine whether there was a significant difference between the variance of the NPCS results and the sulfur capped results, an F-ratio test was used to test the hypothesis

$$H_o: \sigma_N^2 = \sigma_S^2$$

against the alternate hypothesis

$$H_i: \sigma_N^2 \neq \sigma_S^2$$

where: σ_N^2 = variance of NPCS results
σ_S^2 = variance of sulfur capped results

No statistical difference was indicated between the variances of the two capping methods at a 0.05 level of significance. The results are given in Table 4.

11. To test whether the means of the two capping methods were equal, it was assumed that the variances of the two capping methods were equal, based on the previous test. A paired t-test, or z-test, depending on the number of data points in each group, was used to test the hypothesis

$$H_o: \mu_N^2 = \mu_S^2$$

against the alternate hypothesis

$$H_i: \mu_N^2 \neq \mu_S^2$$

where: μ_N^2 = mean of NPCS results
μ_S^2 = mean of sulfur capped results

With the exception of one group of data, there was no significant difference between the means of the two capping methods at a 0.05 level of significance. This indicates that neither capping method gives significantly higher or lower compressive strengths. The results are given in Table 5.

12. The compressive strength values ranged from approximately 500 to 5,500 psi. The average compressive strength was 3,297 and 3,326 psi for the sulfur capped specimens and the NPCS specimens, respectively. A linear regression analysis of the data, using the sulfur capped results as the independent variable and the NPCS results as the dependent variable, indicated a good correlation between the two capping methods for the range of strengths involved. The correlation coefficient was 0.993. The slope of the line obtained from the linear regression analysis was compared to the line of equality. There was a statistical difference between the slopes of the two lines at a 0.05 level of significance. This more severe test indicates that a difference does exist between the two capping methods, even though the difference was not significant in the two previous tests. All data obtained from the linear regression analysis are given in Table 6. A plot of the data, including the line of best fit and the line of equality, is given in Figure 3.

Within-Batch Variation

13. The within-batch variation was determined with all ages combined for each mixture. The average coefficients of variation, average standard deviations, and number of tests exceeding 5 percent variation are given in Table 7. An F-ratio test indicated that for 5 of the 7 mixtures, there was no statistical difference in the variation of the within-batch variability for the two capping methods. A paired t-test, or z-test depending on the number of data points for each mixture, indicated that there was no statistical difference between the means of the two capping methods for the 5 mixtures which had equal variances. This indicates that neither capping method has significantly more or less within-batch variability. The level of significance was 0.05 in each case. The results are given in Table 7.

14. The within-batch variation was determined with all mixtures combined for each age. The average coefficients of variation, average standard deviations, and number of tests exceeding 5 percent variation are given in Table 8. An F-ratio test indicated that at 1- and 28-day ages, there was no

statistical difference in the variances of the within-batch variability for the two capping methods. A z-test indicated that there was no statistical difference between the means of the two capping methods at 1- and 28-day ages. This indicates that neither capping method has significantly more or less within-batch variability. The F-ratio test indicated that there was a statistical difference in the variation of the within-batch variability for the two capping methods at 90-days age. The level of significance was 0.05 in each case. The results are given in Table 8.

Type of Failure

15. The type of failure was not recorded during the testing of these cylinders. Ozyildirim[4] (1985) indicated that splitting failures were common using the NPCS and that shear and conical type failures were common using sulfur mortar caps. Limited laboratory work conducted by the author indicated that when using the NPCS, there was a tendency for a small portion of a corner to shear off upon failure, leaving the cylinder otherwise intact. This phenomenon was especially common on specimens having compressive strengths less than 1,000 psi. Conical failures result, in part, from end friction which tends to confine a portion of each end of a specimen under test. The manufacturer of the NPCS recommends dusting the surfaces of the neoprene pads and of the specimens ends with corn starch prior to testing. This acts as a

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[4] Ozyildirim, C., 1985 (Summer). "Neoprene Pads for Capping Concrete Cylinders," Cement, Concrete, and Aggregates, Vol 7, No 1, pp 25-28.

lubricant[5] which is intended to prolong the life of the neoprene pad. However, it also reduces the end friction and in turn reduces end confinement. Less end confinement also results as the neoprene pad deforms with an increasing load, whereas a sulfur mortar cap is rigid. Splitting failures common with the NPCS are the result of the ability of the ends of the specimen to slide against the cap or deform laterally with the capping material.

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[5] ASTM C 39-86 ε1 requires (Section 7.4) that before a compressive-strength test the operator must "Wipe clean the bearing faces of the upper and lower bearing blocks and of the test specimen." The ASTM Manual of Aggregate and Concrete Testing Section 25.11 through 25.22 give information on capping (Appendix A). It emphasizes that the specimen ends should not be oiled. It is the intent of the test for the specimen to be held rigidly so that the ends do not deform or slide laterally at the contact with the testing machine bearing blocks during the period of load application. The Concrete Manual of the US Bureau of Reclamation (8th Edition, 1975, p 572) says "All foreign material must be removed from the ends of the specimen before testing."

PART IV: CONCLUSIONS

16. The results of this investigation indicate the following:

<u>a</u>. There are no statistical differences in the variances and means between specimens tested for compressive strength using sulfur mortar caps and those tested using the NPCS at a 0.05 level of significance. This indicates that neither capping method gives significantly higher or lower compressive strengths.

<u>b</u>. The linear regression analysis indicated a good correlation between the two capping methods. However, there was a statistical difference between the line of best fit and the line of equality at a 0.05 level of significance. This more severe test indicates that there is a difference in the compressive strengths obtained from the two capping methods, even though there was no statistical difference in the variances and means between the specimens tested using sulfur mortar and those tested using the NPCS. The concrete specimens with sulfur mortar caps gave slightly higher strength values than neoprene capped ones at higher strength levels (over 4,000 psi) whereas the reverse was the case at lower strength levels (below 2,000 psi).

<u>c</u>. In most cases, there was no statistical difference in the within-batch variation of companion specimens tested with sulfur mortar caps and those tested with the NPCS at a 0.05 level of significance.

<u>d</u>. These results are based upon compressive strengths ranging from approximately 500 to 5,500 psi. Within this range, the NPCS appears to be an acceptable alternative to sulfur mortar caps for testing the compressive strength of cylindrical concrete specimens.

<u>e</u>. The NPCS has two advantages over sulfur mortar caps. They are:

(1) Eliminates a safety hazard caused by toxic fumes and the necessity to handle the molten material at high temperatures.

(2) Depending on the number of times that the neoprene pads are reused, the NPCS could constitute a substantial cost savings since applying sulfur mortar to both ends of a specimen is time-consuming and expensive.

17. There is a need for additional work in a controlled laboratory setting to better define the effectiveness of the NPCS. In addition to the variables examined in this study, the following should also be examined:

<u>a</u>. Higher strengths

<u>b</u>. Different size specimens

c. Planeness of top of specimen necessary prior to testing

d. Types of failure

e. Neoprene pads having different hardnesses

f. Number of times that the neoprene pads can be reused

g. Means of preventing sliding lateral or deformation of the end of the specimen under the loading, i.e. achieving end confinement

Table 1

Concrete Mixture Proportions

	SSD Batch Weights for One Cubic Yard								
					Coarse Aggregate				
Mixture	Cement, lb	Fly Ash lb	Water lb	Fine Aggregate lb	3/4-in. lb	1-1/2-in. lb	3-in. lb	WRA, oz	AEA, oz
A-1	316	69	208	1,268	2,036			15	3.5
B-1	288	63	183	1,253	1,096	1,100		14	3.0
C-5	240	51	156	1,034	624	783	1,205	11	2.5
G-2	358	78	164	1,394	1,394	1,897		17	3.0
H	541		242	1,154	1,934			22	4.0
J	358	78	222	1,332	1,888			89*	7.5
B-1X	351		183	1,253	1,096	1,100		14	3.0

* HRWRA

Table 2

Compressive Strength Test Results

Cylinder Number	Age, days	Neopad Compressive Strength, psi	Sulfur Capped Compressive Strength, psi	Mixture
1783E	90	4,490	3,760	A1
1783F	90	4,190	3,900	A1
1792E	90	4,070	3,950	A1
1792F	90	4,050	4,050	A1
1794E	90	4,370	4,590	A1
1794F	90	4,480	4,460	A1
1798E	90	3,810	4,580	A1
1798F	90	3,740	4,040	A1
1802E	90	5,000	4,850	A1
1802F	90	4,840	4,570	A1
1805E	90	5,160	4,750	A1
1805F	90	5,300	4,880	A1
1808E	90	4,390	4,190	A1
1808F	90	4,210	3,790	A1
1816E	90	4,400	4,460	A1
1816F	90	4,170	4,070	A1
1821E	90	3,860	4,030	A1
1821F	90	4,120	4,100	A1
1826E	90	4,760	4,580	A1
1826F	90	4,840	4,620	A1
1837E	90	3,430	3,540	A1
1837F	90	3,790	3,690	A1
1916E	90	4,520	4,440	A1
1916F	90	4,680	4,380	A1
1842E	90	4,440	4,730	B1
1842F	90	4,780	4,570	B1
1876C	28	2,700	2,720	B1
1876D	28	2,610	3,000	B1
1876E	90	3,780	3,900	B1
1876F	90	3,890	3,950	B1
1879C	28	2,930	3,150	B1
1879D	28	2,760	2,590	B1
1879E	90	4,130	4,370	B1
1879F	90	3,910	4,330	B1
1899C	28	2,850	3,230	B1
1899D	28	2,740	2,980	B1
1899E	90	4,340	3,850	B1
1899F	90	4,240	4,320	B1
1900C	28	3,170	3,250	B1
1900D	28	3,050	3,000	B1
1900E	90	4,480	4,280	B1
1900F	90	4,490	4,210	B1
1945A	1	460	550	B1
1945B	1	480	550	B1

(Continued)

Table 2 (Continued)

Cylinder Number	Age, days	Neopad Compressive Strength, psi	Sulfur Capped Compressive Strength, psi	Mixture
1945C	28	2,870	2,870	B1
1945D	28	2,500	2,950	B1
1945E	90	4,150	4,110	B1
1945F	90	4,080	4,150	B1
1948A	1	490	590	B1
1948B	1	450	620	B1
1948C	28	2,900	3,040	B1
1948D	28	3,060	2,990	B1
1948E	90	4,130	4,110	B1
1948F	90	4,180	4,050	B1
1955E	90	3,860	3,850	B1
1955F	90	3,870	3,830	B1
1969A	1	520	590	B1
1969B	1	520	580	B1
1969C	28	2,890	2,980	B1
1969D	28	2,860	3,110	B1
1969E	90	4,440	4,430	B1
1969F	90	4,470	4,340	B1
1973A	1	530	540	B1
1973B	1	550	540	B1
1973C	28	3,480	3,640	B1
1973D	28	3,610	3,480	B1
1973E	90	5,180	4,940	B1
1973F	90	5,230	4,950	B1
1974A	1	540	560	B1
1974B	1	520	540	B1
1974C	28	3,430	3,480	B1
1974D	28	3,190	3,430	B1
1974E	90	4,560	4,700	B1
1974F	90	4,590	4,910	B1
1991A	1	670	750	B1
1991B	1	710	700	B1
1991C	28	3,360	3,240	B1
1991D	28	3,380	3,250	B1
1991E	90	4,480	4,260	B1
1991F	90	4,300	4,200	B1
1992A	1	660	660	B1
1992B	1	660	700	B1
1992C	28	2,910	2,990	B1
1992D	28	2,920	2,930	B1
1992E	90	3,940	3,990	B1
1992F	90	4,050	3,970	B1
1998A	1	460	700	B1
1998B	1	600	700	B1
1998C	28	3,200	2,850	B1

(Continued)

Table 2 (Continued)

Cylinder Number	Age, days	Neopad Compressive Strength, psi	Sulfur Capped Compressive Strength, psi	Mixture
1998D	28	2,910	2,590	B1
1998E	90	4,020	3,770	B1
1998F	90	4,030	3,810	B1
1999A	1	570	750	B1
1999B	1	620	570	B1
1999C	28	3,230	2,930	B1
1999D	28	3,200	2,820	B1
1999E	90	3,960	3,740	B1
1999F	90	3,880	3,740	B1
2010A	1	320	650	B1
2010B	1	530	610	B1
2010C	28	3,300	3,060	B1
2010D	28	3,160	3,200	B1
2010E	90	4,380	4,040	B1
2010F	90	4,370	4,340	B1
2011A	1	390	530	B1
2011B	1	440	560	B1
2011C	28	3,190	3,220	B1
2011D	28	3,220	3,180	B1
2011E	90	3,880	3,970	B1
2011F	90	3,840	3,840	B1
2014A	1	520	610	B1
2014B	1	500	630	B1
2014C	28	2,880	2,870	B1
2014D	28	2,860	2,900	B1
2014E	90	3,970	4,040	B1
2014F	90	4,350	3,980	B1
2015A	1	600	680	B1
2015B	1	620	660	B1
2015C	28	2,920	3,020	B1
2015D	28	3,000	2,960	B1
2015E	90	4,460	4,320	B1
2015F	90	4,950	4,720	B1
2022A	1	550	610	B1
2022B	1	570	650	B1
2022C	28	3,040	3,080	B1
2022D	28	3,030	3,070	B1
2022E	90	4,310	4,740	B1
2022F	90	4,250	4,780	B1
2023A	1	500	590	B1
2023B	1	520	560	B1
2023C	28	2,870	2,850	B1
2023D	28	2,680	2,290	B1
2023E	90	3,920	4,010	B1
2023F	90	4,080	4,080	B1

(Continued)

Table 2 (Continued)

Cylinder Number	Age, days	Neopad Compressive Strength, psi	Sulfur Capped Compressive Strength, psi	Mixture
2029A	1	580	590	B1
2029B	1	600	600	B1
2029C	28	3,210	3,210	B1
2029D	28	2,950	3,010	B1
2029E	90	4,510	4,420	B1
2029F	90	4,550	4,080	B1
2032A	1	470	530	B1
2032B	1	490	520	B1
2032C	28	3,010	2,940	B1
2032D	28	2,970	3,020	B1
2032E	90	4,350	4,360	B1
2032F	90	4,300	4,320	B1
2042A	1	550	590	B1
2042B	1	560	590	B1
2042C	28	2,680	2,750	B1
2042D	28	2,770	3,080	B1
2042E	90	4,250	3,840	B1
2042F	90	3,760	3,810	B1
2043A	1	590	570	B1
2043B	1	580	560	B1
2043C	28	2,820	2,730	B1
2043D	28	2,740	2,890	B1
2043E	90	3,800	3,830	B1
2043F	90	3,920	3,560	B1
2049A	1	710	730	B1
2049B	1	690	700	B1
2049C	28	3,420	3,070	B1
2049D	28	3,060	3,150	B1
2049E	90	4,270	4,340	B1
2049F	90	4,220	4,270	B1
2050A	1	610	700	B1
2050B	1	600	730	B1
2050C	28	3,180	3,370	B1
2050D	28	3,050	3,250	B1
2050E	90	4,210	4,200	B1
2050F	90	4,300	4,370	B1
2053A	1	650	630	B1
2053B	1	680	700	B1
2053C	28	2,920	3,100	B1
2053D	28	2,320	3,290	B1
2053E	90	4,290	4,280	B1
2053F	90	4,430	4,240	B1
2056A	1	580	660	B1
2056B	1	580	710	B1
2056C	28	2,730	2,880	B1

(Continued)

Table 2 (Continued)

Cylinder Number	Age, days	Neopad Compressive Strength, psi	Sulfur Capped Compressive Strength, psi	Mixture
2056D	28	2,900	3,020	B1
2056E	90	4,300	4,150	B1
2056F	90	4,110	4,160	B1
2068A	1	570	540	B1
2068B	1	570	580	B1
2068C	28	2,710	2,850	B1
2068D	28	3,040	2,880	B1
2068E	90	4,370	3,880	B1
2068F	90	4,000	4,080	B1
2071A	1	600	600	B1
2071B	1	600	640	B1
2071C	28	3,160	3,100	B1
2071D	28	3,000	3,140	B1
2071E	90	4,360	3,750	B1
2071F	90	3,860	3,890	B1
1930E	90	4,860	4,260	C5
1930F	90	4,930	4,540	C5
1972A	1	510	620	C5
1972B	1	580	630	C5
1972C	28	3,330	3,330	C5
1972D	28	3,200	3,200	C5
1972E	90	4,560	4,270	C5
1972F	90	4,380	4,360	C5
1787E	90	5,210	4,760	G2
1787F	90	5,430	4,790	G2
1869E	90	5,010	4,850	G2
1869F	90	4,950	4,950	G2
1890E	90	4,740	4,780	G2
1890F	90	4,830	4,620	G2
1896E	90	4,310	4,270	G2
1896F	90	4,380	4,220	G2
1910E	90	5,080	4,780	G2
1910F	90	4,980	4,560	G2
1919E	90	5,760	5,530	G2
1919F	90	5,710	5,380	G2
1952E	90	4,530	4,220	G2
1952F	90	4,560	4,310	G2
1962E	90	4,820	4,850	G2
1962F	90	4,930	4,850	G2
1965F	90	4,700	6,090	G2
1965F	90	4,910	4,710	G2
1881E	90	4,890	4,480	H
1881F	90	4,830	4,510	H
1886E	90	5,600	5,020	H
1886F	90	5,610	5,690	H

(Continued)

Table 2 (Concluded)

Cylinder Number	Age, days	Neopad Compressive Strength, psi	Sulfur Capped Compressive Strength, psi	Mixture
1889E	90	4,700	4,980	H
1889F	90	5,070	4,900	H
1893E	90	5,800	5,380	H
1893F	90	5,880	5,490	H
1905E	90	4,390	4,340	H
1905F	90	4,410	4,310	H
1926E	90	4,690	4,730	H
1926F	90	4,800	4,750	H
1937E	90	4,830	4,530	H
1937F	90	4,890	4,610	H
1949E	90	4,940	4,680	H
1949F	90	4,990	4,720	H
1846E	90	4,440	4,320	J
1846F	90	4,480	4,320	J
1855E	90	4,870	4,880	J
1855F	90	4,860	4,750	J
1922E	90	4,980	4,910	J
1922F	90	4,680	4,780	J
1934E	90	4,920	4,820	J
1934F	90	5,030	4,620	J
1941E	90	4,780	4,680	J
1941F	90	4,870	4,590	J
1944E	90	4,760	4,640	J
1944F	90	4,730	4,690	J
1961E	90	4,620	4,520	J
1961F	90	4,820	4,670	J
2036A	1	1,490	1,590	B1X
2036B	1	1,530	1,530	B1X
2036C	28	3,310	3,180	B1X
2036D	28	3,350	3,260	B1X
2036E	90	5,290	5,420	B1X
2036F	90	5,120	5,290	B1X
2037A	1	1,520	1,580	B1X
2037B	1	1,410	1,540	B1X
2037C	28	3,160	3,380	B1X
2037D	28	3,300	3,340	B1X
2037E	90	5,310	5,150	B1X
2037F	90	5,260	5,220	B1X

Table 3

Linear Regression Analysis of Compressive Strength Data

Number of data pairs =	131	psi
Average sulfur capped strength =	3,297	psi
Average neoprene pad capped strength =	3,326	psi
Slope of line =	1.04	
Correlation coefficient =	0.993	
Y-intercept =	-106	psi
X-intercept =	102	psi
Standard error of estimate =	183	psi
Estimated variance of the slope =	0.0011	
Estimated variance of the intercept =	1,482	
Estimated standard error of estimate of the slope (ESEES) =	0.0106	
t = (slope - 1)/ESEES =	3.77	
$t_{0.25}$ =	1.96	

Table 4

Summary of Compressive Strength Data

Mix Age Cap	No. of Samples	Mean	σ	Range	Coeff Var.
A1 90					
N	24	4361.3	474.01	1870.0	10.869
S	24	4261.3	383.95	1340.0	9.010
B1 1					
N	50	558.6	80.00	390.0	14.322
S	50	620.0	65.84	230.0	10.614
B1 28					
N	58	2991.4	248.86	1290.0	8.319
S	58	3044.0	209.95	1050.0	6.897
B1 90					
N	62	4238.7	314.22	1470.0	7.413
S	62	4178.2	326.56	1390.0	7.816
B1X 1					
N	4	1487.5	54.89	120.0	3.657
S	4	1560.0	29.44	60.0	1.887
B1X 28					
N	4	3280.0	82.87	190.0	2.526
S	4	3290.0	88.69	200.0	2.696
B1X 90					
N	4	5245.0	85.83	190.0	1.636
S	4	5270.0	115.18	270.0	2.186
C5 1					
N	2	545.0	49.50	70.0	9.082
S	2	625.0	7.07	10.0	1.131
C5 28					
N	2	3265.0	91.92	130.0	2.815
S	2	3265.0	91.92	130.0	2.815

(Continued)

Table 4 (Concluded)

Mix Age Cap	No. of Samples	Mean	σ	Range	Coeff Var.
C5					
90					
N	4	4682.5	257.73	550.0	5.504
S	4	4447.5	160.70	350.0	3.613
G2					
90					
N	18	4935.6	402.36	1450.0	8.152
S	18	4806.7	476.32	1870.0	9.910
H					
90					
N	16	5020.0	460.22	1490.0	9.168
S	16	4820.0	405.33	1380.0	8.409
J					
90					
N	14	4774.3	173.19	590.0	3.628
S	14	4656.4	179.30	590.0	3.851

Table 5

Hypothesis Concerning Two Variances

H_o: $\sigma_N^2 = \sigma_S^2$
H_1: $\sigma_N^2 \neq \mu_S^2$

Mix	Age	$F_{.975}$	F Calculated
A1	90	2.31	1.52
B1	1	1.78	1.23
B1	28	1.68	1.41
B1	90	1.67	1.08
B1X	1	15.44	3.41
B1X	28	15.44	1.15
B1X	90	15.44	1.80
C5	1	647.80	49.02
C5	28	647.80	0
C5	90	15.44	2.57
G2	90	2.68	1.40
H	90	2.86	1.29
J		3.12	1.07

Cannot reject H_o
can assume $\sigma_N^2 = \sigma_S^2$

Table 6

Hypothesis Concerning Two Means

H_o: $\mu_N^2 = \mu_S^2$

H_i: $\mu_N^2 \neq \mu_S^2$

Mix Age	$Z_{.025}$	Z Calculated	$t_{.025}$	t Calculated	Comment
A1 90	1.96	0.80			Cannot reject H_o
B1 1	1.96	-4.19			Reject H_o
B1 28	1.96	-1.23			Cannot reject H_o
B1 90	1.96	1.05			Cannot reject H_o
B1X 1			2.447	-0.348	Cannot reject H_o
B1X 28			2.447	-0.165	Cannot reject H_o
B1X 90			2.447	-2.344	Cannot reject H_o
C5 1			4.303	-2.26	Cannot reject H_o
C5 28			4.303	0	Cannot reject H_o
C5 90			2.447	1.55	Cannot reject H_o
G2 90	1.96	0.88			Cannot reject H_o
H 90	1.96	1.30			Cannot reject H_o
J			2.056	1.77	Cannot reject H_o

Table 7

Within-Batch Variation, All Ages Combined for Each Mix

Mix	Avg Coefficient of Variation Neo	Avg Coefficient of Variation Sul	Avg Std. Dev. Neo	Avg Std. Dev. Sul	Number Exceeding 5% variation Neo	Number Exceeding 5% variation Sul
A1	2.40	2.58	1.59	2.03	1 of 12	1 of 12
B1	2.93	3.58	3.98	3.72	15 of 85	23 of 85
C5	4.93	2.08	4.43	0.98	1 of 4	0 of 4
G2	1.87	4.17	1.17	7.03	0 of 9	1 of 9
H	1.70	2.27	2.10	3.59	1 of 8	1 of 8
J	2.06	2.01	1.92	1.25	1 of 7	0 of 7
B1X	2.94	2.04	2.14	0.85	1 of 6	0 of 6

Test $H_o: \sigma^2_{N_2} = \sigma^2_{S_2}$

$H_i: \sigma_N \neq \mu_S$

Mix	$F_{.975}$	F_{cal}	
A1	3.48	1.63	*Cannot reject* H_o, assume $\sigma^2_{N_2} = \sigma^2_{S_2}$
B1	1.53	1.14	Cannot reject H_o, assume $\sigma_N = \sigma_S$
C5	15.44	20.43	Reject H_o
G2	4.43	36.10	Reject H_o
H	4.99	2.92	Cannot reject H_o, assume $\sigma^2_{N_2} = \sigma^2_{S_2}$
J	5.82	2.36	Cannot reject H_o, assume $\sigma_{N_2} = \sigma_{S_2}$
B1X	7.15	6.34	Cannot reject H_o, assume $\sigma_N = \sigma_S$

Test $H_o: \mu^2_{N_2} = \mu^2_{S_2}$

$H_i: \mu_N \neq \mu_S$

Mix	$Z_{.025}$	Z_{cal}	$t_{.025}$	t_{cal}
A1	1.96	-0.24		
B1	1.96	-1.10		
H			2.145	-0.39
J			2.179	0.06
B1X			2.228	0.96

Table 8

Within-Batch Variation, All Mixes Combined for Each Age

Age	Avg Coefficient of Variation Neo	Avg Coefficient of Variation Sul	Avg Std. Dev. Neo	Avg Std. Dev. Sul	Number Exceeding 5% variation Neo	Number Exceeding 5% variation Sul
1	4.00	4.21	6.07	4.56	6 of 28	9 of 28
28	3.08	3.78	2.80	3.45	5 of 32	9 of 32
90	2.11	2.63	1.83	3.31	8 of 71	9 of 71

Test $H_o: \sigma_N^2 = \sigma_S^2$
$H_1: \sigma_N^2 \neq \mu_S^2$

Age	$F_{.975}$	F_{cal}	
1	2.16	1.77	Cannot reject H_o, assume $\sigma_N^2 = \sigma_S^2$
28	2.07	1.52	Cannot reject H_o, assume $\sigma_N^2 = \sigma_S^2$
90	1.65	3.38	Reject H_o

Test $H_o: \mu_N^2 = \mu_S^2$
$H_1: \mu_N^2 \neq \mu_S^2$

Age	$Z_{.005}$	Z_{cal}	
1	1.96	-0.15	Cannot reject H_o
28	1.96	-0.89	Cannot reject H_o

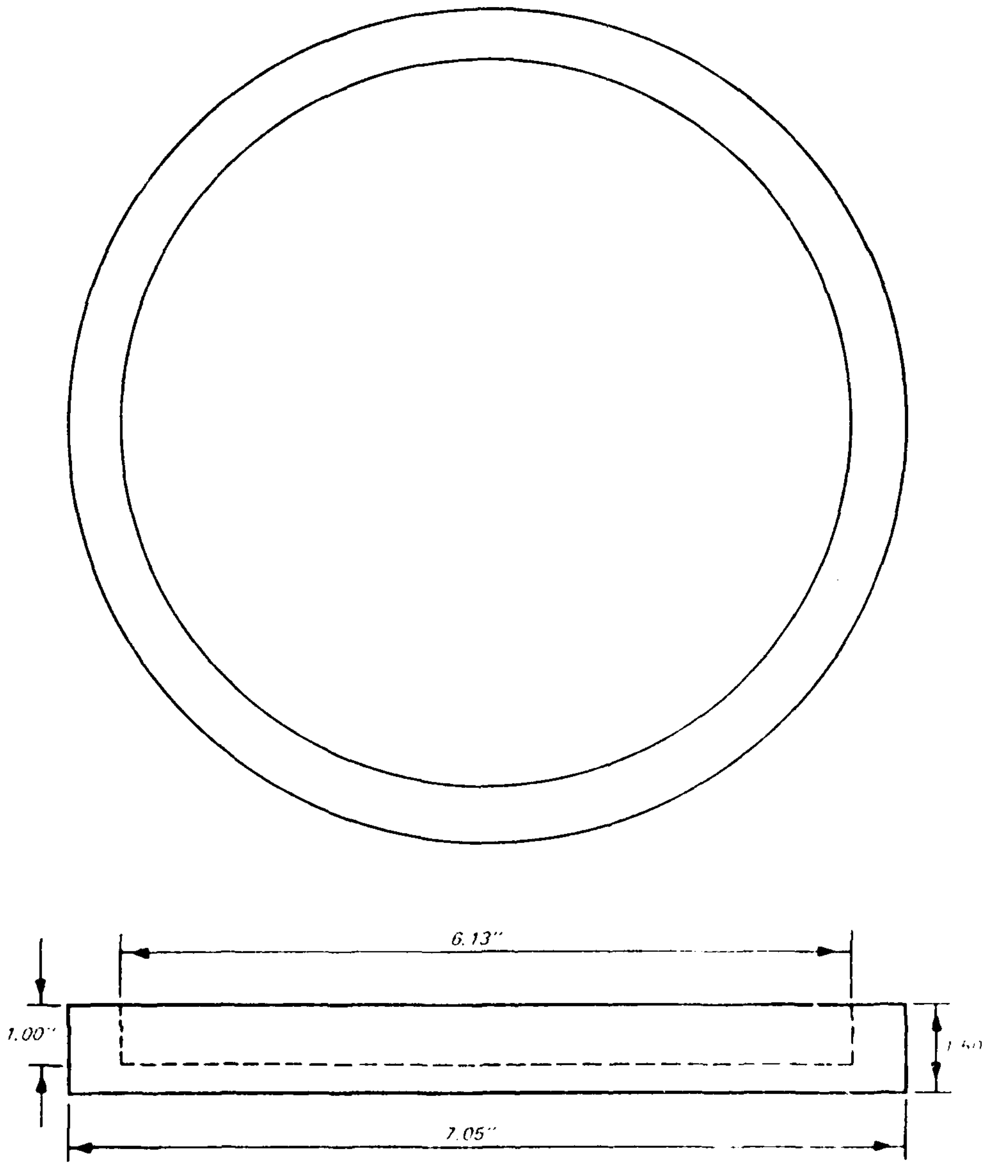

Figure 1. Steel retainer cap

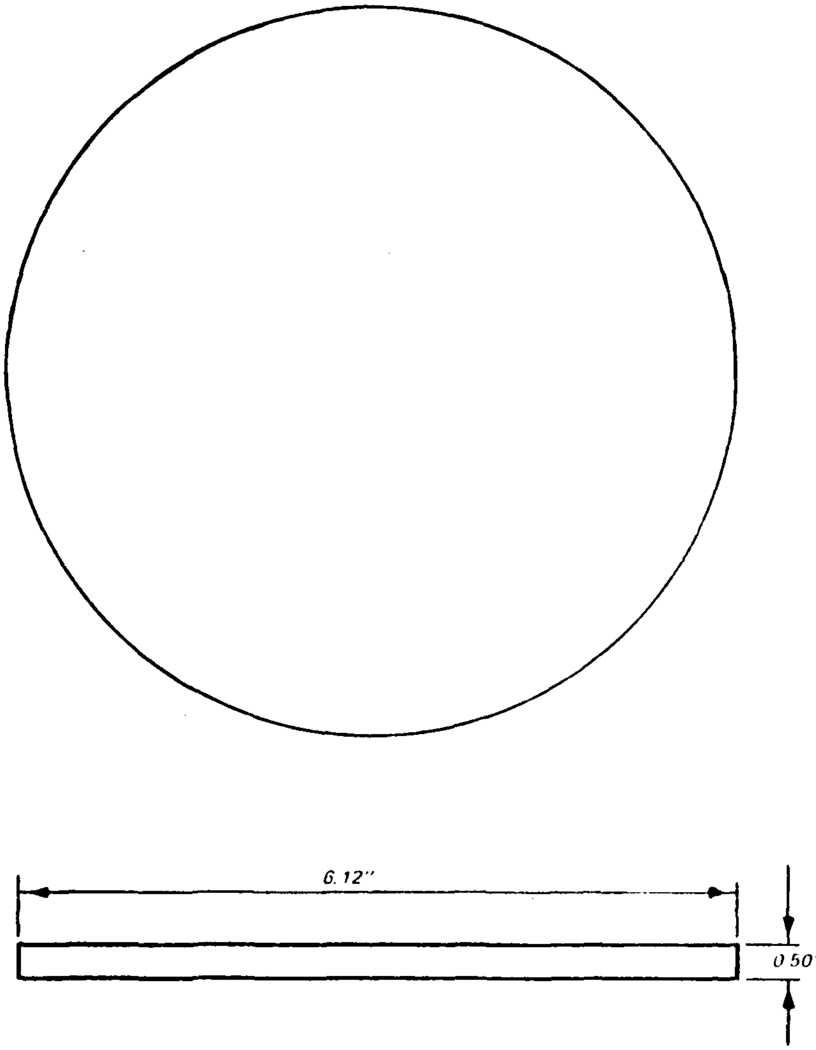

Figure 2. Neoprene pad

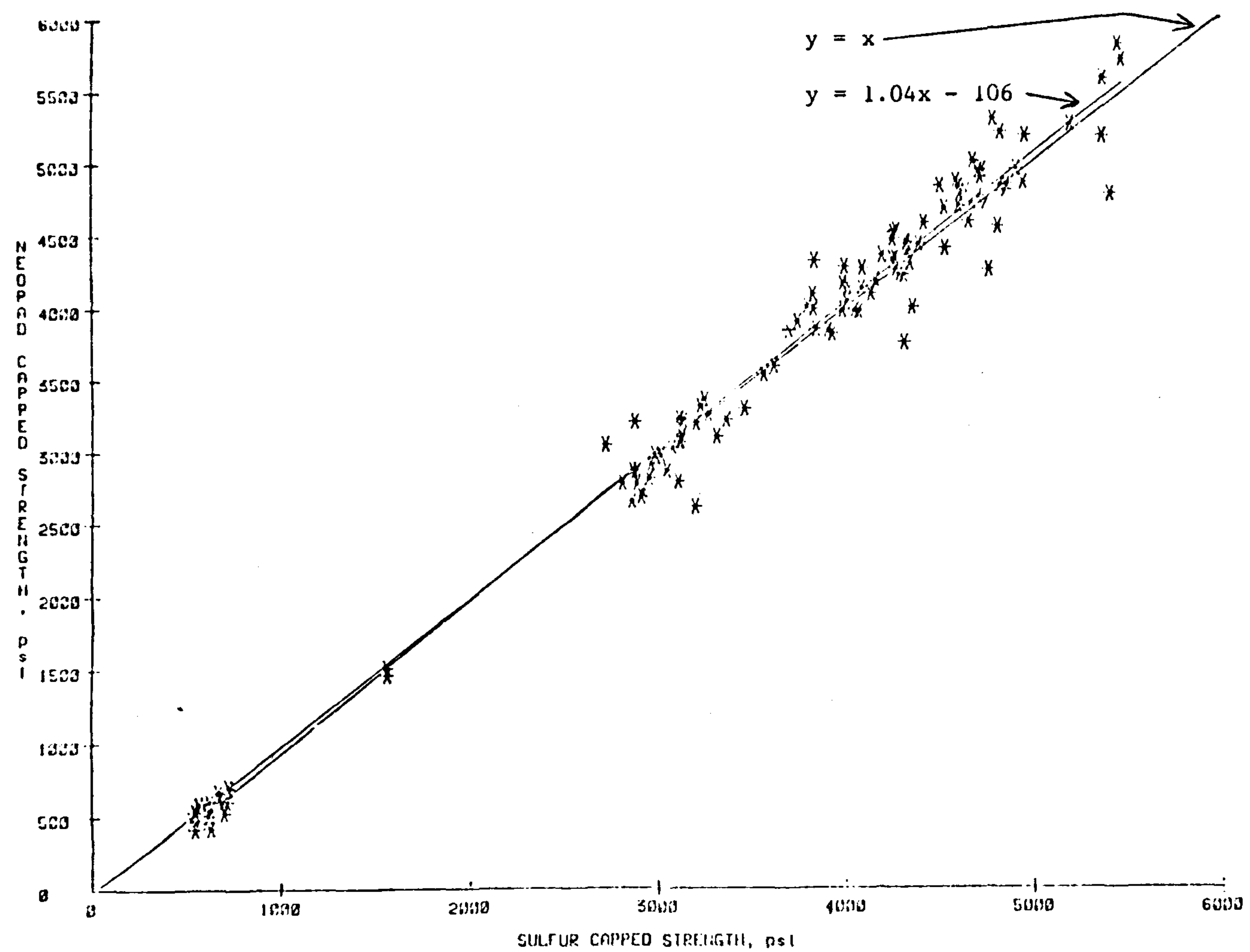

Figure 3. Correlation between sulfur capped strength and NPCS strength

APPENDIX A: MANUAL OF AGGREGATE AND CONCRETE TESTING (ASTM, 1987)

25.11 The capping of cylinders on one or both ends prior to test may not be necessary under some conditions. If a machined metal plate of the required planeness (0.002 in. (0.05 mm) or less) is used at the bottom of metal molds, and if the top of the cylinder be capped with neat cement paste using a glass or metal plate of required planeness and thickness, the cylinder ends might be satisfactory without further treatment. However, the ends of a cylinder should always be checked with a straightedge. Careless rodding of the first layer in a cylinder mold can damage the plane surface of a machined metal plate.

25.12 ASTM C 617, Standard Practice for Capping Cylindrical Concrete Specimens, does allow for the composition of the mixture of sulfur and granular materials for capping. It is required that the sulfur mortar shall have a compressive strength of at least 5,000 psi (34.5 MPa) at 2 hr. Two-inch (51-mm) cubes of the sulfur mortar should be tested, using the procedure of Practice C 617 as a guide in molding the test specimens. Sulfur cements gain strength with age. For some materials, a 2-hr strength with age. For some materials, a 2-hr strength of 5,000 psi may increase to 9,000 psi (62.1 MPa) at 24 hr. Strengths are considerably lower at an age less than 2 hr.

25.13 Sulfur mortar, either laboratory prepared or commercial type, can sometimes produce rubbery caps that deform or flow under load. Such undesirable behavior can be caused by a plasticizer in the commercial material, or by contamination of either type with oil, grease, paraffin, or by overheating. A concrete cylinder with a heavy coating of paraffin on the bottom end, sometimes caused from a heavy layer of paraffin in the bottom of a cardboard mold, should not be capped until the wax has been removed. The ends of concrete cylinders should not be oiled before capping with sulfur mortar, as is done in some laboratories to facilitate the removal of caps from tested cylinders. In any case, the use of reclaimed or inferior homemade sulfur mortar mixtures is not recommended unless the material is frequently checked for strength and deformation under load.

25.14 The required waiting period of at least 2 hr between capping and

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Annual Book of ASTM Standards, 1987. Section 4, Volume 04.02, "Concrete and Mineral Aggregates; pp 869-908.

testing of cylinders capped with sulfur mortar should be strictly enforced unless a sacrifice of apparent strength is allowable as expedient in job control of detensioning of prestressed concrete.

25.15 When cylinders are capped with sulfur mortar the ends of the cylinders must be dried to avoid steam pockets under the cap. During drying and in the process of capping considerable moisture can be lost from the cylinder. This can be prevented by storing the cylinder in moist air, under water, or by wrapping in several layers of wet burlap until time of test. Cylinders should never be allowed to dry for several hours before capping nor for 2 hr or more before testing.

25.16 Some sulfur mortars warp or crack on cooling, and caps made with them may also crack, or fail to adhere to the cylinders, and may not meet the planeness requirement of 0.002 in. (0.05 mm). Such undesirable properties have been observed in caps made with homemade mixtures having an exceptionally high sulfur content. If tapping with a light flat metal hammer upon a sulfur mortar cap produces a hollow sound, an unsatisfactory cap is indicated. Sulfur mortar caps should be as thin as practicable. A vertical capping device usually produces thinner caps than can be secured with a horizontal apparatus. Cylinder ends that are very uneven or highly convex should be rubbed down with a carborundum rubbing stone, or should be squared by cutting with an abrasive or diamond saw before capping. Regardless of the type of capping material used, the ends of highly uneven cylinders should be squared as outlined above; this is particularly important if sulfur mixtures or high-strength gypsum plaster is used.

25.17 The plates of the capping apparatus should be oiled or greased lightly before use, but the ends of the test specimens should not be oiled before applying the sulfur mortar caps. When specimens are held in the vertical position during capping, pour enough of the molten sulfur mortar into the recessed plate and then quickly press the test cylinder into the compound, which will solidify in about 1/2 min. Plates should be neither too hot nor too cold. Cold plates will produce thick caps and should be warmed by pouring one or two caps before the first cylinder is capped. If plates are hot, caps will harden slowly and extra plates may be helpful. Capping plates should be occasionally checked with a straightedge to determine whether the plates meet the planeness requirements in ASTM C 617. Figure A2 shows the planeness of

caps being checked with a 6-in. (152-mm) machinist's parallel and a .002-in. (.05-mm) feeler gage of the required thickness. The planeness of capping plates is similarly checked periodically. The caliper and the scale shown in Figure A2 are used to measure the diameter of the cylinder to calculate the area in accordance with ASTM C 39, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. Such checking does not eliminate the necessity of checking planeness of capped specimens since the capping plates may warp when they are heated.

25.18 A suitable container and source of heat must be provided for melting the sulfur mortar and maintaining the proper temperature of about 260°F (127°C). See Section 3.3 of ASTM C 617. Such material should flow freely at the proper temperature. If the material thickens from overheating, it must be cooled and stirred until thin. In most instances, cooling will restore the mixture to a satisfactory condition if it is stirred during cooling. If it is greatly overheated, it should be tested for strength before use. Melting apparatus should be of suitable design, electrically heated with automatic controls, and provided with thermal safety melting links. Electric contacts should be protected from sulfur fumes. The melting pot should be under a hood with forced ventilation to the outside air. The use of a small air-driven stirring device in the molten material will help to maintain the uniformity of the material. A small chain with a bolt or the like in the end suspended in the pot when cooling or a metal rod will provide a ready means of holding the hardened center of the sulfur mortar above the bottom of the pot when the next reheated. It will be helpful to a smooth operation if the ladle is kept in the pot during capping. A large perforated sheet metal strainer or spoon is helpful in removing small lumps of unmelted material.

25.18.1 A heavy gage steel lip around the container may aid in protecting the pot when hardened sulfur mortar is chipped from around the edges. Severe burns have resulted from explosion of sulfur mortar being heated over a hot plate when the material in the bottom of the pot melted and boiled before the surface had melted, causing a build-up of pressure. In one case reported, it was thought that the explosion might not have happened if the metal ladle had been left in the pot, as was the usual custom. The ladle apparently acts somewhat as a safety device by conducting heat up from the bottom of the pot and thereby melting a relief channel and preventing build-up pressure. Heating elements mounted on the walls of the pot, have been found satisfactory.

25.18.2 Operators who handle hot sulfur mortar should wear leather faced cotton or asbestos work gloves, face shield or safety glasses, and long sleeves. A tight cover for the pot or wet burlap bags should be at hand in case of fire. Fire is unlikely in thermostatically controlled equipment heated electrically. Overheating for a long time may permanently damage the mixture. If water or moist material gets into the melting pot, foaming may occur. The area near the melting pot should be checked for flammables or explosive gases. A fire extinguisher of the dry chemical type should be at hand. Sulfur burns with a low, blue flame. ASTM C 386, Standard Practice for Use of Chemical-Resistant Sulfur Mortars, is a useful reference.

25.19 Certain problems and precautions are connected with the use of high-strength gypsum plasters for capping. ASTM C 617 permits the use of such plaster for capping concrete specimens expected to have a compressive strength below 5,000 psi (34.5 MPa), provided the plaster has a compressive strength of 5,000 psi or greater when tested as 2-in. (51-mm) cubes and mixed to the same consistency as used in the capping. The mixture water used should be between 26 to 30%. The temperatures of air and mixing water during the capping should be substantially the same as those that prevailed when tests of the high strength gypsum were made. Free water on the surface of the concrete can tend to soften the gypsum cap, and therefore, all free water should be removed before applying the cap. After the cylinder has been capped, it should be wrapped immediately in several layers of moist burlap, but the capped end or ends should not be covered. It takes about 20 min for such caps to harden, but specimens must not be tested until the material develops the required strength. Caps should be as thin as practicable, and a vertical capping jig is advisable to obtain thin and parallel caps at right angles to the axis of the cylinder.

25.20 Capping plates, whether metal or glass, should meet the planeness requirements in Section 3.1 of ASTM C 617. Plate glass, 1/4 in. (6.4 mm) thick, 7 by 7 in. (180 by 180 mm) can be obtained with a planeness of 0.002 in. (0.05 mm) in any 7-in. dimension. Plain metal plates can be ground to planeness within 0.002 in., but a recessed plate, as usually supplied with the vertical capping device. Periodic resurfacing will be required and this should be considered in selecting plate thickness. Glass capping plates should be at least 1/4 in. (6.4 mm) thick, and all edges should be ground smooth.

25.21 Caps made by hydraulic cement, either portland or high alumina, have certain advantages for moist-cured concrete specimens, but constant moisture conditions must be maintained during the setting of the neat cement pastes and the curing of the hardened caps. Lack of moisture, and absorption of moisture from the paste by the dry concrete can result in caps that are cracked, nonplane, or of poor strength. Hydraulic cement caps must be kept moist at all times to prevent cracking, and must be aged sufficiently so that they will exceed the strength of the concrete being tested. Caps should never be made with straight sulfur, ordinary plaster of paris, or a mixture of plaster of paris and portland cement. A mixture of either plaster of paris and portland cement or high-strength gypsum plaster and portland cement can have a strength considerably lower than either of its constituents.

25.22 The need for capping is not required if the ends of the hardened concrete cylinders are ground or lapped to the prescribed planeness. This method is not mentioned in ASTM C 31, Standard Method of Making and Curing Concrete Test Specimens in the Field, or ASTM C 617 and its drawbacks are cost and lack of skilled operators and proper apparatus. If grinding wheels are used, goggles should be worn. If the grinding process produces dust, provision should be made to collect such dust as a safety measure.

Figure A1. Typical conical fracture expected from the compressive strength test

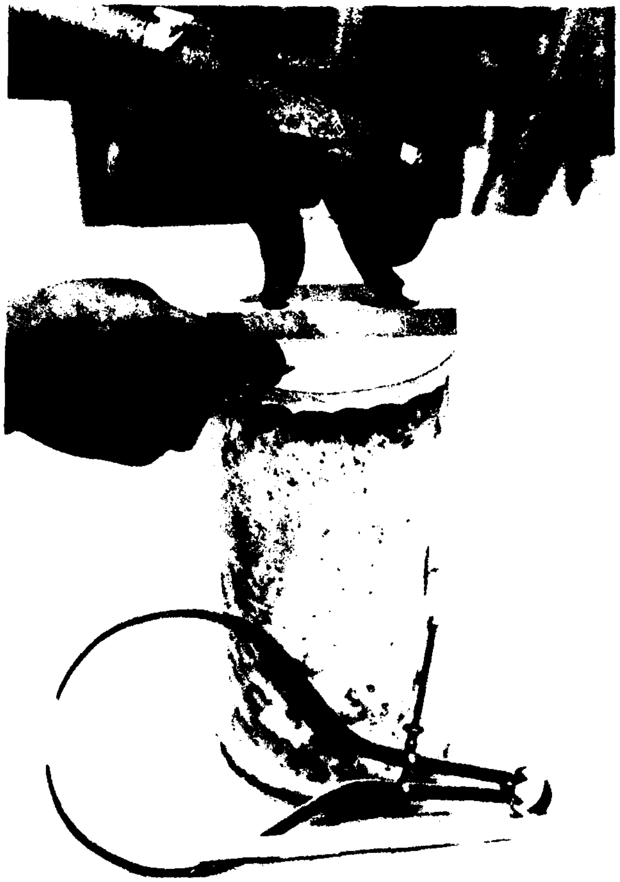

Figure A2. Checking planeness of the capped end of a concrete cylinder before testing

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